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THE USE OF LANDSAT-1 IMAGERY IN MAPPING AND MANAGING SOIL AND RANGE RESOURCES IN THE SAND HILLS REGION OF NEBRASKA

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16. Abstract

Evaluation of ERTS-1 imagery for the Sand Hills Region of Nebraska has shown that the data can be used to effectively measure several parameters of inventory needs. (1) Vegetative biomass can be estimated with a high degree of confidence using computer compatable tape data. (2) Soils can be mapped to the subgroup level with high altitude aircraft color infrared photography and to the association level with multitemporal ERTS-1 imagery. (3) Water quality in Sand Hills lakes can be estimated utilizing computer compatable tape data. (4) Center pivot irrigation can be inventoried from satellite data and can be monitored regarding site selection and relative success of establishment from high altitude aircraft color infrared photography. (5) ERTS-1 data is of exceptional value in wide-area inventory of natural resource data in the Sand Hills Region of Nebraska.

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HISTORY

This project involves a study of the application of LANDSAT-1 imagery in the interpretation of natural resources and environmental conditions within the Sand Hills region of Nebraska.

The Sand Hills occupy approximately 52,000 square kilometers (20,000 sq. miles) of the north-central third of the state of Nebraska, constituting the largest continguous area of sand dunes in the western hemisphere. Unlike many dune areas, however, the Sand Hills are stabilized by native grasses and the region comprises the largest continuous expanse of grassland in the Great Plains. This expanse of grassland is used predominantly for the production of beef cattle, with cow-calf operations as the principal form of livestock enterprise. The eolian sands that make up the majority of soils of the Sand Hills demand exceedingly careful management of these grasslands, primarily because they are highly susceptible to wind erosion. Despite the fragility of the area, in 1972 it supported 518,300 cows and 606,700 calves and yearlings, representing an aggregate value of $263,820,000.

The ability of the Sand Hills region to support such animal numbers is due, in part, to the hydrology of the area. This region contains the largest groundwater reserve in the

Great Plains and has a greater rate of groundwater recharge than any other upland area of comparable size in the Missouri River Basin. The near-surface hydrology results in lakes or subirrigated meadow areas interspersed between the dominant dune features. Land areas of significant elevation above the water table are well-drained and subject to drought conditions, since precipitation is from 16 to 24 inches annually and is very irregular over the region. Management practices in caring for the vegetation are complicated by the contrasting abundance of water or lack of it, depending on topographic location in relation to the water table.

Recent irrigation technology has resulted in renewed interest in the groundwater resources of the Sand Hills region. Center-pivot sprinkler systems allow irrigated production of forage and feed grains on some of the well-drained soils of the region. The rapidity with which this technology is being applied throughout this region is resulting in the need for evaluation of land for center-pivot irrigation. In addition, avoiding undesirable changes in environment due to groundwater fluctuations is as important as the desire to enhance the economics of the region through the use of center-pivot irrigation.

Since the primary geological material across the Sand Hills region is eolian sand, patterns of soil and vegetation result mainly from differences in topography and near-surface hydrology. Mappable areas of vegetation and soils, although irregular in shape, often occupy from several hundred acres to several square miles. The dominant land use--ranching--has not appreciably altered the basic patterns of plant communities. The relatively uniform composition of surface sediments as well as stable vegetative communities and relatively large mappable areas make the Sand Hills region well suited to evaluation by remote sensing techniques.

Ranch units in the Sand Hills region average 4,000 hectares (10,000 acres) in size, making general public accessibility to most of the land unnecessary. This lack of intensive land use provided little incentive to develop detailed groundwater, soil, and vegetation surveys for much of the area. This inaccessability and lack of detailed surveys of the Sand Hills makes it difficult to accumulate knowledge on a regional basis. With today's emphasis on conservation of natural resources and environmental quality, it is becoming imperative to look at entire regions in order to provide comprehensive evaluation, monitoring, and planning.

ACCOMPLISHMENTS

Collection of Ground Truth

Establishment of transects. The relative inaccessibility of much of the Sand Hills region required the selection of transects and study sites on these transects to obtain field data. Transects paralleling four major north-south highways across the region were established. The highways--U. S. 183 and 83 and State 61 and 250--provided easy access to study sites and a discernible ground feature from which to locate sites on aircraft overflight photography. Transect width of 24 kilometers (15 miles) was restricted to coverage available with one overflight of NASA RB-57 aircraft. Figure 1 shows transect locations in relation to the region.

Selection of sites. Field reconnaissance for study site selection began in June 1972. Since NASA RB-57F aircraft photography taken June 1, 1972, was not received until September 1, 1972, study sites were selected without prior knowledge of their suitability based on the study of aircraft photography. Delay in launch of LANDSAT-1 from March 31, 1972, to July 23, 1972, also resulted in the unavailability of LANDSAT imagery as a basis of judgment in site selection.

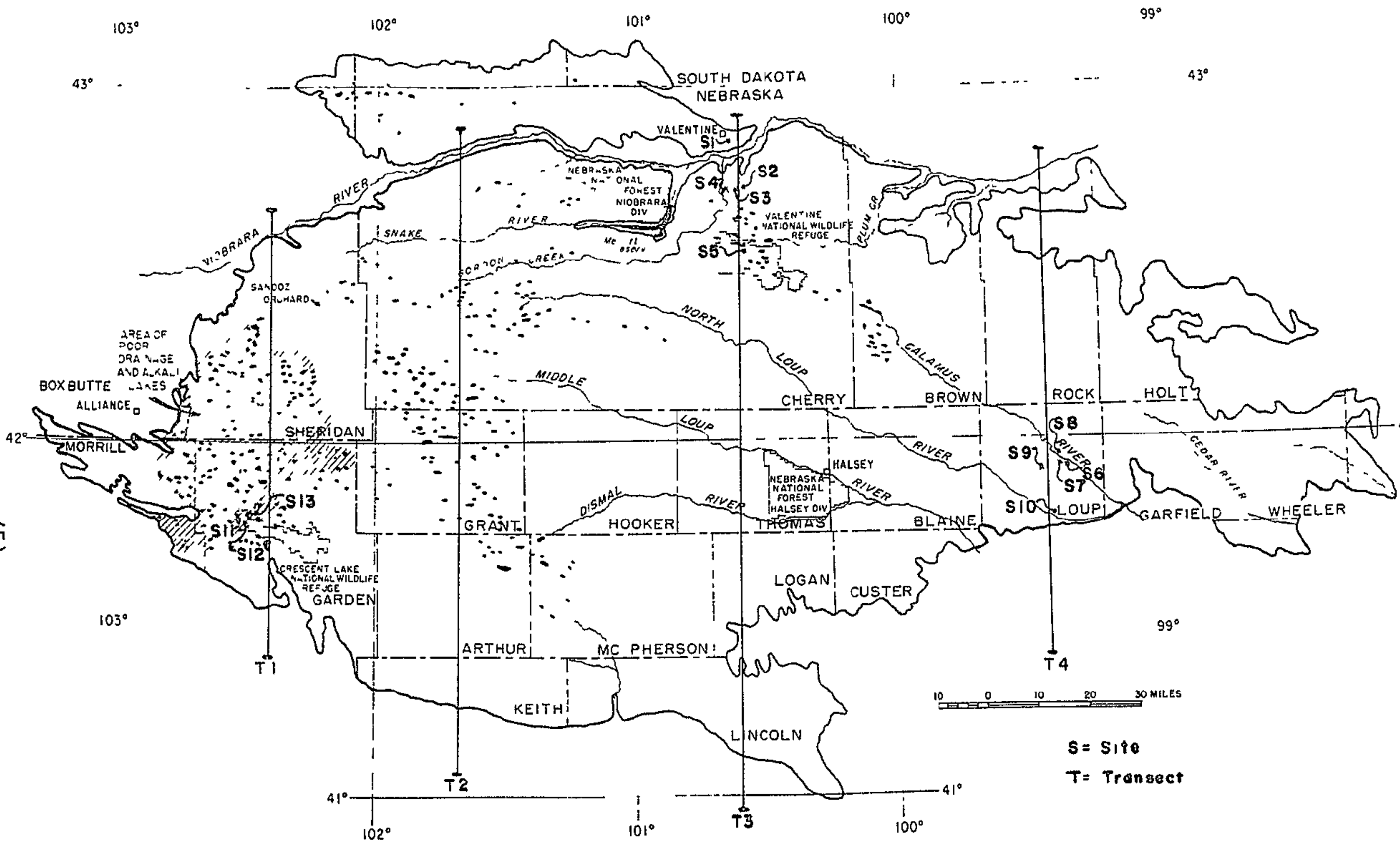


Figure 1. Map of Sand Hills Region Showing Transects of RB-57F Flights and Range Sites Chosen for Sampling.

Assuming predicted resolution limits of 100 meters (300 ft.) for the satellite imagery, and considering the relatively irregular shape of many of the potential study sites, an arbitrary minimum limit of 80 hectares (200 acres) was established for study sites. However, attempts were made to select sites of 120 hectares (300 acres) or greater in size. Because of irregular soil pattern within the Sand Hills, the size of available areas in one or more site categories was a limiting factor. The term "site categories" is used here to indicate grouping of individual range sites, as defined by the U. S. Department of Agriculture's Soil Conservation Service (USDA-SCS Technical Guide) into units predicted to be suitable for visual interpretation of aircraft photography and LANDSAT imagery. Site categories chosen were: (1) sands-choppy sands, (2) sandy, and (3) subirrigated-wetland. In some cases, the rangeland management unit (that area bounded by one continuous fence within which the study site was located) included more than one site category. In these instances, the predominant site category was sampled for ground truth.

Excellent cooperation from District Conservationists of the Soil Conservation Service, U. S. Department of Agriculture, and Refuge Managers of the Fish and Wildlife Service, U. S. Department of the Interior, resulted in selection of thirteen study sites concentrated in three areas of the Sand Hills. Five sites were located north of Taylor, Nebraska, in the eastern Sand Hills; five south of Valentine, Nebraska, centrally located; and three north of Oshkosh, Nebraska (all on Crescent Lake National Wildlife Refuge), near the western edge of the Sand Hills. Figure 1 shows the locations of selected sites. Where possible, similar range sites of varying condition class (i.e., good sandy site and poor sandy site) were selected as test sites in the same area. This allowed for evaluation of differences in forage density within a site category as well as forage density differences between site categories.

Documentation in the form of color and color infrared ground photographs was obtained during all phases of site selection. This provided a permanent record of the sites and a basis for comparing selected study sites with other sites within the region.

Soil profiles. Since the primary geological material making up the Sand Hills is eolian sand, the soils are not complicated by gross lateral changes in the lithology of surface sediments. Previous investigations by various state and federal agencies provided characterization data for the typical soils of the region. The intent of our soil profile studies was to confirm that characteristic soils within our study sites were typical of the major soils of the region.

Pits were dug to expose the soil profile. Soil characteristics--such as color, texture, structure, and horizons composing the soil profile--were recorded using standard soil classification terminology. In the case of subirrigated sites, the depth to the water table was determined by auguring a small diameter hole to the depth required. Slope and other pertinent terrain features were also recorded. Color photographs were taken of representative soil profiles for a permanent record and for comparison with other sites.

Typical soil profiles associated with study sites are described in tables 1, 2 and 3. Valentine fine sand (table 1) is representative of soils found on the sands-choppy sands range sites. Dunday loamy fine sand (table 2) is representative of soils found on sandy range sites. Elsmere loamy fine sand (table 3) represents soils found on subirrigated range sites. Wetland range sites have a water table within 91.4 cm (36 inches) of the surface, whereas subirrigated range sites have a water table from 25.4 to 152.4 cm (10 to 60 inches) below the surface during a major part of the growing season. Occurrence of a water table more than 152.4 cm (60 inches) below the surface generally removes the influence of the water table from most rangeland plants in the Sand Hills.

Table 1. Description of Soil Profile of Valentine Fine Sand Soil Type.

Site No. 12 - Described August 7, 1973.

Slope - 3% on dune top, 15% off the dune sides

Soil type - Valentine fine sand

Profile

A1	0-4"	light brownish gray (10YR 6/2), (10YR 4/2 moist), fine sand, weak very fine granular structure, very friable, noncalcareous, clear wavy boundary.
AC	4-7"	pale brown (10YR 6/3), (10YR 4/3, moist), fine sand, structureless single grain, loose, noncalcareous, gradual wavy boundary.
C	7-42" +	light gray (10YR 7/2), (10YR 5/2, moist), fine sand, structureless single grain, loose, noncalcareous.

Table 2. Description of Soil Profile of Dunday Loamy Fine Sand Soil Type.

Site No. 6 - Described August 9, 1973.

Slope - 0-2%

Soil type - Dunday loamy fine sand.

Profile

A1	0-7"	grayish brown (10YR 5/2), (10YR 3/2, moist), loamy fine sand, weak, fine granular structure, friable moist noncalcareous abrupt wavy boundary.
AC	7-11"	light brownish gray (10YR 6/2) dry (10YR 4/2, moist), weak very fine granular structure, loose, noncalcareous, clear wavy boundary.
C	11-50"	light gray (10YR 7/2), (10YR 6/2, moist), fine sand, structureless single grain, loose, noncalcareous.

Table 3. Description of Soil Profile of Elsmere Loamy Fine Sand Soil Type.

Site No. 3 - Described August 8, 1973.

Slope - 0-1%

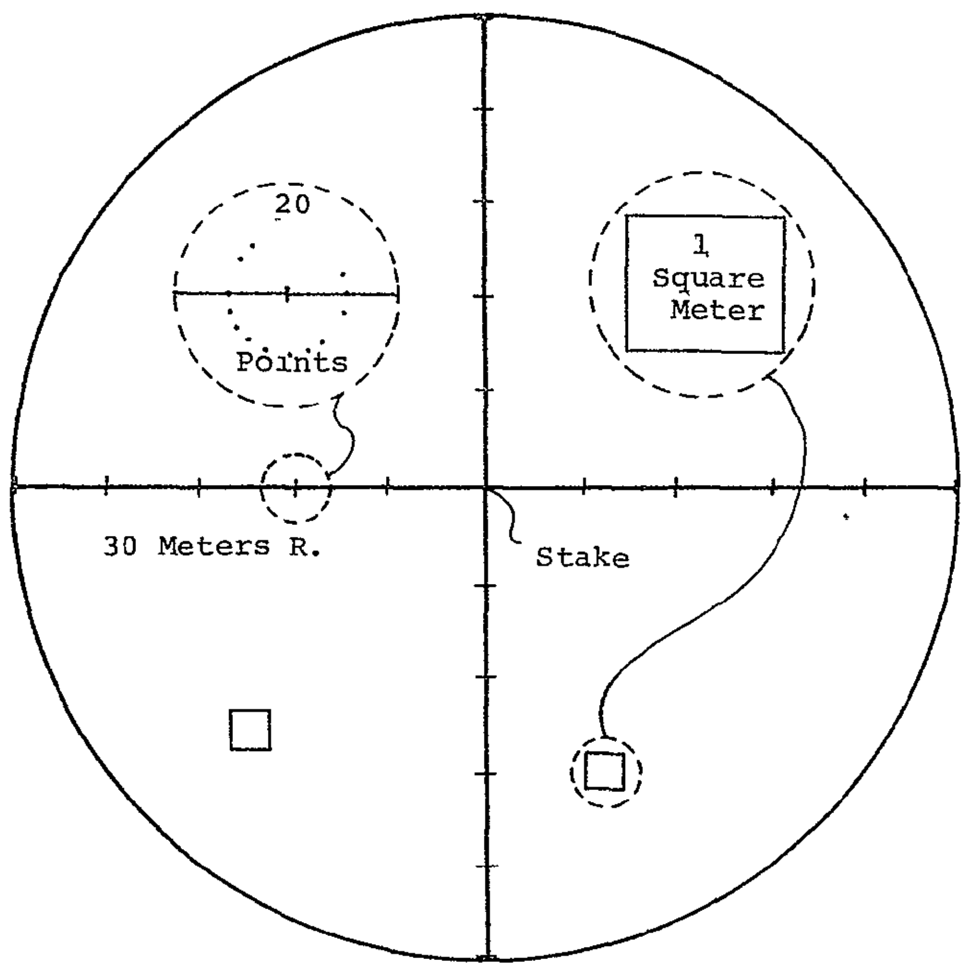
Soil type - Elsmere loamy fine sand.

Profile

A11	0-4"	grayish brown (10YR 5/2), (10YR 3/2, dry), loamy fine sand, weak very fine granular structure, very friable moist, loose dry, noncalcareous, abrupt wavy boundary.
A12	4-10"	grayish brown (10YR 5/2), (10YR 4/2, moist), loamy fine sand, weak very fine granular structure, very friable moist, loose dry, noncalcareous, clear wavy boundary.
C	10-52"	pale brown (10YR 6/3), (10YR 5/2, moist), fine sand with few fine faint yellowish brown (10YR 5/4) mottles, structureless single grain, loose, noncalcareous, abrupt wavy boundary.
Ab	52-60"	dark gray (10YR 4/1), moist loamy fine sand, structureless single grain, loose, noncalcareous.

Vegetative survey. A detailed vegetative survey was completed for twelve of the thirteen sites selected for study. Sampling was carried out using a focal point apparatus and an array of points determined by a rope and compass system originating from a central stake. Figure 2 shows the layout of the sampling procedure. The central stake was used as the permanent marker for the site. Each

Figure 2. Sampling Procedure for Field Measurement of Vegetative Biomass and Vegetative Inventory Data.



of the four directions was a cardinal point of the compass, determined by a standard field compass held over the central stake. A 30-meter (100-foot) rope, with knots tied every 6 meters (20 feet), was then stretched to correspond to the cardinal points. The focal point apparatus was then placed over each of the four knots and the end point of the rope farthest from the stake. At each of the five locations, twenty sampling points were taken at equally spaced points in a circle about the location. Points were recorded as bare soil, litter or the specific species of vegetation indicated by the point. Litter is defined as nonliving vegetative material originating from other than the current growing season.

The focal point apparatus is an ordinary surveyor's transit modified to view in a vertical direction and focus within the distance of the height of the instrument. To view vertically, the optics tube is removed from the mounts and attached to an arm, such that when the arm is mounted in the normal optics tube position, the view is vertically downward. This form of attachment allows the arm to be rotated on the compass table of the instrument, as the optics tube formerly rotated. Arm length may be varied according to the needs of the operator. An additional lens is inserted into the optics tube to shorten the focus distance to the range necessary for viewing the ground or vegetation above ground.

Placement of the instrument for sampling is such that the center of the compass table is vertically over the knot of the rope and the compass table is as level as is possible in a reasonably short period of adjustment.

The crosshair intersection of the optics tube determined the point to be recorded in the survey. Once a familiarity with the vegetation on a site was established, most vegetative identifications could be made through the optics of the instrument. In some cases, however, locating and picking the actual plant for identification was necessary.

Biomass clipping data. Limitations of time and travel did not allow sampling of all sites for vegetative biomass data for all satellite overpasses during the growing season. Consequently, efforts to collect data were concentrated on the five sites south of Valentine, Nebraska. Vegetative biomass data were collected from all sites where vegetative survey data and soil profile descriptions were taken.

Initial experience during the summer of 1972 indicated that clippings from 1 square meter of site area provided a manageable amount of vegetation for biomass measurements. This size of sampling area also allowed for flexibility in selection of areas for clipping to include species proportions representative of the entire site. A square meter outline of cord and stakes was placed over the selected area and all vegetation with the square meter was clipped just above the soil surface. Clippings were placed in an ordinary paper bag and the paper bag placed in a larger plastic bag. The plastic bag prevented loss of moisture until a fresh weight could be obtained for the sample. Fresh weights were usually taken with four hours of clipping. Samples were oven-dried at 80° C overnight and dry weights then taken. A number of samples were then separated into current year's growth and previous growth. This separation indicated the proportion of the sample that was live vegetation capable of providing near infrared reflectance.

Photographic documentation in the form of color and color infrared slides was taken periodically at each site. Panoramic views as well as near-vertical closeups of the vegetation were recorded. Visual observations concerning grazing use, phenological stages of vegetation and general site condition were also recorded.

Lake Water Quality

The relationship of lake water quality to reflectance differences shown by selected Sand Hills lakes was also evaluated. Water samples taken by personnel of the Nebraska Game and Parks Commission were analyzed by the water quality laboratory of the Department of Agronomy, University of

Nebraska-Lincoln. Table 4 lists the water quality parameters measured during analysis. Samples were taken at four different dates during the open water period of 1973. Table 4 also lists the lakes sampled.

Additional documentation in the form of field notes and ground-level photography (color and color infrared) was also taken at the time of water sampling. This documentation was utilized to related possible differences in reflectance to emergent and/or submergent aquatic vegetation.

Evaluation of High Altitude Aircraft Photography

Recognition of Range Sites

Studies utilizing color infrared aerial photography (Cihacek and Drew, 1970) showed that plant communities on the sand dunes and intervening valleys of the Sand Hills region differ in their ability to reflect near-infrared radiation. Since a range site is a specific combination of soil type and plant community, it was anticipated that range sites could be delineated. Range sites also differ in density of plant cover, however, because of topographic conditions or deterioration of forage production capability (lowering of condition class). Differences in density of plant cover on color infrared photography are enhanced

Table 4. Water Analyses

SAMPLE SITE	Sample Dates 6-29-73	8-2-73	9-16-73	11-29-73	Average
			Carbonates, PPM		
Merritt Reservoir	0	5.3	0	---	1.8
Dewey Lake	5.3	---	0	0	1.8
Clear Lake	13.2	27.1	0	15.8	14.0
Big Alkali Lake	41.6	54.1	35.6	40.3	42.9
Ell Lake	23.1	73.3	43.6	56.8	49.2
Willow Lake	106.3	147.2	150.5	138.6	135.7
			Bicarbonates, PPM		
Merritt Reservoir	112.6	101.8	108.5	---	107.6
Dewey Lake	230.5	226.5	239.9	262.6	239.9
Clear Lake	467.7	443.5	489.1	483.7	471.0
Big Alkali Lake	816.1	809.4	873.7	829.5	832.2
Ell Lake	708.9	639.2	576.3	652.6	644.3
Willow Lake	1935.0	2205.6	1541.0	953.7	1908.8
			Calcium, PPM		
Merritt Reservoir	10.4	12.3	21.5	---	14.7
Dewey Lake	33.4	37.4	41.0	44.0	39.0
Clear Lake	22.4	22.4	33.6	33.4	28.0
Big Alkali Lake	10.8	8.1	17.0	17.9	13.5
Ell Lake	9.0	6.0	16.5	16.7	12.1
Willow Lake	54.0	13.8	24.4	191.1	70.8
			Sodium, PPM		
Merritt Reservoir	7.4	8.6	7.7	---	7.9
Dewey Lake	14.9	17.0	16.4	15.7	16.0
Clear Lake	60.7	65.4	62.0	66.8	63.7
Big Alkali Lake	175.2	194.4	192.0	196.8	189.6
Ell Lake	109.8	127.3	102.7	128.1	117.0
Willow Lake	370.0	481.6	364.0	412.0	406.9
			Magnesium, PPM		
Merritt Reservoir	3.1	3.4	3.7	---	3.4
Dewey Lake	6.5	7.0	7.9	7.4	7.2
Clear Lake	24.1	25.9	28.5	29.5	27.0
Big Alkali Lake	36.5	38.6	43.3	43.3	40.4
Ell Lake	31.8	35.8	34.9	38.4	35.2
Willow Lake	26.1	12.7	9.9	48.2	24.2

Table 4 (Cont'd.)

SAMPLE SITE	Sample Dates 6-29-73	8-2-73	9-16-73	11-29-73	Average
			Potassium, PPM		
Merritt Reservoir	6.6	6.8	6.3	---	6.6
Dewey Lake	14.4	14.6	20.8	15.8	16.4
Clear Lake	62.5	65.0	61.6	63.6	63.2
Big Alkali Lake	94.8	102.5	101.0	94.8	98.3
Ell Lake	125.7	140.4	116.9	132.3	128.8
Willow Lake	349.4	451.6	316.7	357.2	368.7
			PH		
Merritt Reservoir	8.0	8.6	7.2	---	7.9
Dewey Lake	8.5	8.1	7.9	8.0	8.1
Clear Lake	8.7	8.7	8.3	8.6	8.6
Big Alkali Lake	9.0	8.9	8.9	8.9	8.9
Ell Lake	8.8	9.1	9.1	9.1	9.0
Willow Lake	9.0	9.2	9.4	9.3	9.2
			Conductivity (m mhos)		
Merritt Reservoir	.22	.20	.19	---	.20
Dewey Lake	.34	.34	.35	.41	.36
Clear Lake	.71	.70	.71	.81	.73
Big Alkali Lake	1.32	1.31	1.37	1.40	1.35
Ell Lake	1.18	1.18	1.37	1.21	1.14
Willow Lake	2.85	3.65	2.93	3.41	3.21

because of the total spectral response of the underlying sandy soil. With these factors in mind, visual evaluation of color infrared acquired by high-altitude aircraft photography was made to determine if known range sites could be identified.

Location of known range sites on the photography was relatively easy, because of the ease of distinguishing ground features near to or associated with the sites. Close examination of the photography indicated that the range site categories listed in the section dealing with site selection could be readily recognized.

Forage Density

Evaluation of high-altitude color infrared photography taken by NASA RB-57 aircraft from 60,000 feet was also carried out to determine if differences in forage density could be observed. Two types of forage density phenomena were visible: (1) fenceline contrasts where management differences resulting in differing levels of forage utilization were apparent on one site divided by a fence, and (2) condition class differences where production levels of existing vegetation are different for the two sites compared, the two sites being in the same site category.

Soil Subgroup Delineation

To determine the relationship between vegetative patterns and associated soils, comparisons were made between existing soils maps and the high altitude color infrared photography. Existing soils maps were photographically reduced to the same scale as the aerial photography on clear-base positive transparencies. These transparencies were then laid over the aerial photography. In general, there was a good relationship between vegetative patterns on the photography and soil mapping units as delineated on the soils map.

Additional comparisons were made by combining all mapping units indicated as being associated with the previously defined range site categories. An overlay for the sands-choppy sands category and the subirrigated wetlands category was prepared and superimposed on the color infrared photography. In each case, the overlay delineated those areas that would be interpreted as belonging to that range site category. Table 5 shows the relationship between soils and range sites considered in the evaluation. Attempts to relate individual soil mapping units to vegetative patterns was not as successful.

Table 5. Relationships of Major Physiographic Features, Soil Associations, and Range Sites Within the Sand Hills Region of Nebraska.

PHYSIOGRAPHIC FEATURE	SOIL CLASSIFICATION SERIES	SOIL CLASSIFICATION SUBGROUP	RANGE SITE
Steeply Sloping Uplands	Valentine, hilly	Typic Ustipsamment	Choppy Sands
Rolling Uplands	Valentine, rolling	Typic Ustipsamment	Sands
Uplands	(Blow-out land*)		Sands
Dry Valleys	Dunday	Entic Haplustoll	Sandy
Dry Valleys	Anselmo	Typic Haplustoll	Sandy

Table 5 (cont'd.)

PHYSIOGRAPHIC FEATURE	SOIL CLASSIFICATION SERIES	SUBGROUP	RANGE SITE
Subirrigated Valleys	Elsmere	Aquic Haplustoll	Subirrigated
Subirrigated Valleys	Gannett	Typic Haplaquoll	Subirrigated
Subirrigated Valleys	Gannett, ponded	Typic Haplaquoll	Wet Land
Shallow Water	(Marsh*)		

* Land Type

Center Pivot Irrigation Systems

The high resolution capabilities of high-altitude color infrared photography allowed for the evaluation of the relative degree of success of established center-pivot irrigation systems. In cases where color infrared aerial photography was available prior to establishment of the system, criteria for selection of sites could be determined and related to probable success of establishment. The photography further served as an intermediate level of data to relate to the evaluation of imagery. Type of crop cover, for example, was more readily documented with the aid of the aerial photography.

Evaluation of LANDSAT Imagery

Individual Wave Bands

All wave length bands of the multispectral scanner (MSS) aboard LANDSAT-1 were evaluated visually in terms of distinguishing ground features of interest in the project. Band 5 proved to be the most useful wavelength for distinguishing vegetative differences and cultural practices within the Sand Hills. Bands 6 and 7 provided the most information regarding surface water and wetlands. Most often a combined evaluation of bands 5 and 6 or 5 and 7 provided the maximum information, with band 5 contributing the majority of the necessary data. Winter imagery with snow cover and low sun angle show a marked enhancement of topography, with little apparent difference among bands.

Various methods of enlargements of the 9 x 9 inch and 75 millimeter positive transparencies were tested for additional extraction of information. Overhead projectors and lanternslide projectors were used for direct optical enlargement. Success of optical enlargement through projection was dependent primarily on the texture and whiteness of the projection surface. Generally, the smoother and whiter the surface, the clearer the projected image. Quality lenses were always a prerequisite to clarity in enlargement. A distinct disadvantage to projection was the impossibility of obtaining any sort of permanent record of interpretations, except by tracing on an appropriate background. Projection did provide for rapid quick-look assessments of various enlargements. Further evaluation generally required photographic enlargement of the portion of the scene containing the area of interest.

Photographic enlargement proved to be a very useful tool for individual wave band interpretation. Standard photographic equipment and procedures were used. It required the additional step of producing a negative, but this did not appear to detract significantly from the detail of the image. Enlargements up to eight times the original scale of 1:1,000,000 were routinely used to delineate various ground features.

Densitometer Measurements of Imagery from Band Five

Vegetative differences within the Sand Hills rangeland were most easily recognized on band 5 imagery. In general, the greater the image density, the greater the vegetative density on the ground. The relationship between optical density of the imagery and vegetative biomass as determined by clipping data was investigated. Optical density of 9 x 9 inch positive transparencies was measured with a Macbath "Quanta-Log" densitometer with a 1 mm light orifice. Locations were pinpointed by a "crosshair" overlay that was removed after positioning on the densitometer and prior to reading the density. Meter readings were manually recorded with reference to the area being evaluated. Water bodies were not always readily distinguishable on band 5. Comparison with band 7 was necessary to determine if an area contained water bodies.

Interpretations from Bands Six and Seven

The near-infrared bands provided the greatest detail in interpretation of surface water and wetlands. Greater variation in density was expressed, according to visual interpretation, in band 6 for surface water in comparison with the same scene in band 7. Utilization of the near-infrared bands made it easy to distinguish lakes from adjacent marsh or subirrigated areas, an interpretation that was not consistently possible with band 5 imagery.

Projector/Viewer Color Composites

A Spectral Data Model 61 Projector/Viewer was obtained to investigate the usability of color composites for soil and vegetative interpretation. Limited success was achieved with a viewer. In most instances it was quite difficult to register simultaneously all portions of the three wavelength bands used. Some portion of the image could be registered without too much difficulty, necessitating several manipulations to study an entire scene.

A photographic process was necessary to obtain permanent records of projected or the viewer-screen composites. This resulted in some loss of detail and accurate recording of interpretational data was not always possible.

Diazochrome Color Composites

The technique of preparing color composites by use of diazochrome materials proved to be much more satisfactory than color composites generated with the Projector/Viewer. Since the process produces individual wave band copies by contact printing, little detail is lost. Multiband registry was not a significant problem with this technique. A most distinct advantage was that the process resulted in a permanent copy that could be further manipulated by projection or photographic processes. Variation in exposure time allowed for variation in intensity of individual bands in a manner similar to varying the intensity of individual bands with the Projector/Viewer. Availability of a range of colors suggests the further possibility of color enhancement in a manner analogous to changing filter colors in a Projector/Viewer.

Evaluation of color composites showed their use in interpretation to be similar to that of color infrared photography. In general, resolution of the imagery appeared to be about one-tenth that of the high-altitude color infrared photography. Assuming adequate site size, range site categories were identifiable in much the same manner as on the photography. Subirrigated-wetland sites were easily distinguished from other sites, as well as from adjacent water. The mottled color pattern of sands-choppy sands sites was distinguishable from the more uniform color of the sandy sites, but not as readily as on the aircraft photography.

Cooperation with Great Plains Corridor Project

Contributions to Project

Cooperation was extended to the project "Monitoring the vernal advancement and retrogradation (green wave effect) of natural vegetation," MMC 667, directed by Dr. J. W. Rouse, Jr., Remote Sensing Center, Texas A & M University, College Station, Texas. Ground data were obtained at the five sites south of Valentine, Nebraska, and forwarded to the Texas A & M project.

Vegetative data obtained in this cooperative effort were obtained in essentially the same manner as biomass clipping data described in the Accomplishments section. Additional field data in the form of phenological stages of vegetation, weather data, and grazing program for the test sites were recorded. Photographic documentation, as four specified ground scenes, was recorded at each sampling date for each site sampled.

SIGNIFICANT RESULTS

Delineation of Soil Association

Multitemporal Imagery for Interpretations of Soil Associations

One objective of this study was to test the hypothesis that shadow patterns from dune topography and spectral reflectance of the rangeland vegetation would allow interpretations of soil associations from reflectance measured by sensors abroad LANDSAT 1. The major soils of the Sand Hills region represent a hydrosequence, and soil patterns are closely associated with differences in topography, near-surface hydrology, and rangeland vegetation. Preliminary evaluation of imagery for the region indicated spring imagery to be optimum for determining vegetative differences, whereas winter imagery with low sun angle and snow cover provided the best view of topographic differences. Initial interpretations of soil associations were made using field data from recently published soil association maps and detailed soil maps of Hooker County, Thomas County, and McPherson County, Nebraska, to provide training for visual interpretations. In addition, landscape photographs of soil associations within these counties were taken from an aircraft flying at an altitude of 300 meters above the ground and soil profiles were examined at selected locations in the field.

Images of portions of the Sand Hills region obtained during overpasses of LANDSAT 1 on January 9, 1973, and on May 14, 1973, were used for the interpretations. Enlargements of system corrected images at a scale of 1:125,000 in bands 4, 5, 6, and 7 as well as diazochrome color composites generated from bands 4, 5, and 6 were interpreted visually. Recognition of topographic features, stream drainage patterns, soil drainage and land use were indicated by differences in pattern, shadow, tone texture, and color on the images.

Major soil taxonomic units recognized and defined in the Sand Hills region are listed in Table 5. Valentine (somewhat excessively drained) and Dunday and Anselmo (well drained) occur in areas where the groundwater table is well below the surface. Elsmere (somewhat poorly drained) and Loup and Gannett (poorly drained) are limited to subirrigated locations. Soil associations delineated in the published soil surveys of Hooker, Thomas, and McPherson counties are defined in terms of these soil series and attendant topographic features or subirrigated conditions (table 6).

Table 6. Relationships of Topographic Features, Soil Associations, and Range Sites Within the Sand Hills Region of Nebraska

TOPOGRAPHIC FEATURES	SOIL ASSOCIATIONS	RANGE SITES
1. Rolling and steeply sloping (choppy) uplands with dry valleys	Valentine-Dunday	Sands, Choppy Sands, and Sandy
2. Rolling uplands with dry valleys	Valentine-Anselmo	Sands and Sandy
3. Steeply sloping (choppy) uplands	Valentine, hilly	Choppy Sands
4. Rolling uplands with subirrigated valleys	Valentine-Elsmere-Gannett	Sands and Subirrigated
5. Rolling uplands, dry valleys and subirrigated valleys	Valentine-Dunday-Loup	Sands, Sandy, Subirrigated
6. Rolling uplands	Valentine, rolling	Sands
7. Rolling uplands with dry valleys of sand hills - loess border	Anselmo-Valentine-Dunday	Sands, Sandy

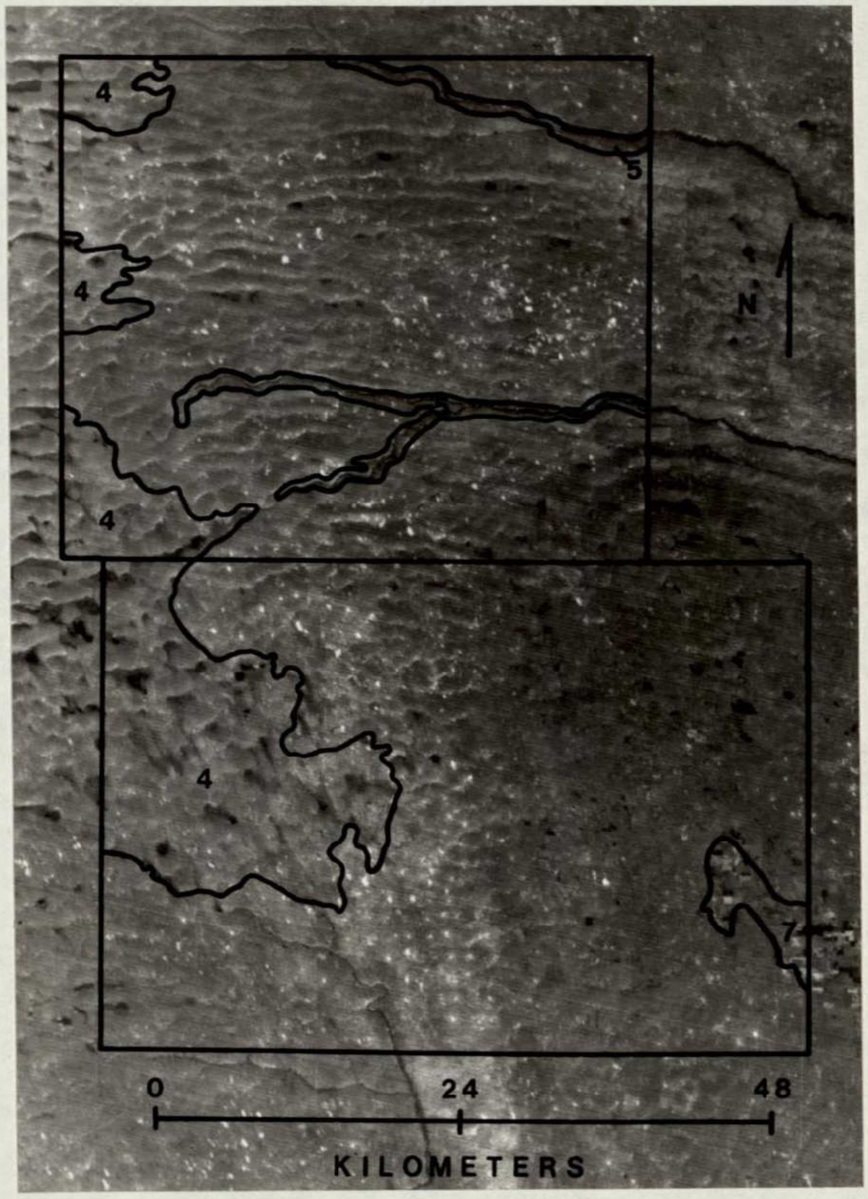
Because of the drainage sequence represented by these soils, the distribution of rangeland plant communities is closely related to soil patterns. Valentine, Anselmo, and Dunday support primarily warm-season grasses, while Elsmere supports a mixture of warm- and cool-season grasses. Loup and Gannett support a dense cover of sedges and cool-season grasses. During spring and early summer, the dense stands of sedges and cool-season grasses associated with Elsmere, Loup, and

Gannett soils use greater amounts of visible red light in photosynthesis than vegetation on adjacent soils where the groundwater table is well below the root zone. This utilization results in less reflectance of visible red light and hence darker tones on the band 5 images for the subirrigated areas. The resulting reflectance pattern allows separation of the subirrigated valleys from the surrounding dry valleys and uplands (figure 3).

Conversely, near infrared reflectance was greatest from the dense vegetation of the subirrigated Elsmere, Loup, and Gannett soils than from vegetation on Valentine, Dunday, and Anselmo soils. Thus, a color composite generated from imagery obtained in bands 4, 5, and 6 on May 14, 1973, to enhance the interpretation of near-infrared reflectance confirmed the separation of the subirrigated soils from the well-drained or somewhat excessively drained soils. This separation was not always possible, however, on imagery obtained subsequent to the removal of vegetation from subirrigated soils during summer haying operations and prior to significant regrowth.

Reflectance patterns on band 5 images acquired on May 14, 1973, permitted delineation of the Valentine-Elsmere-Gannett association in areas where subirrigated Elsmere and Gannett occur between dunes, and the Valentine-Dunday-Loup

Figure 3. Soil Associations in McPherson and Hooker Counties which Involve Subirrigated Soils, both Interdunal and Along Drainageways.

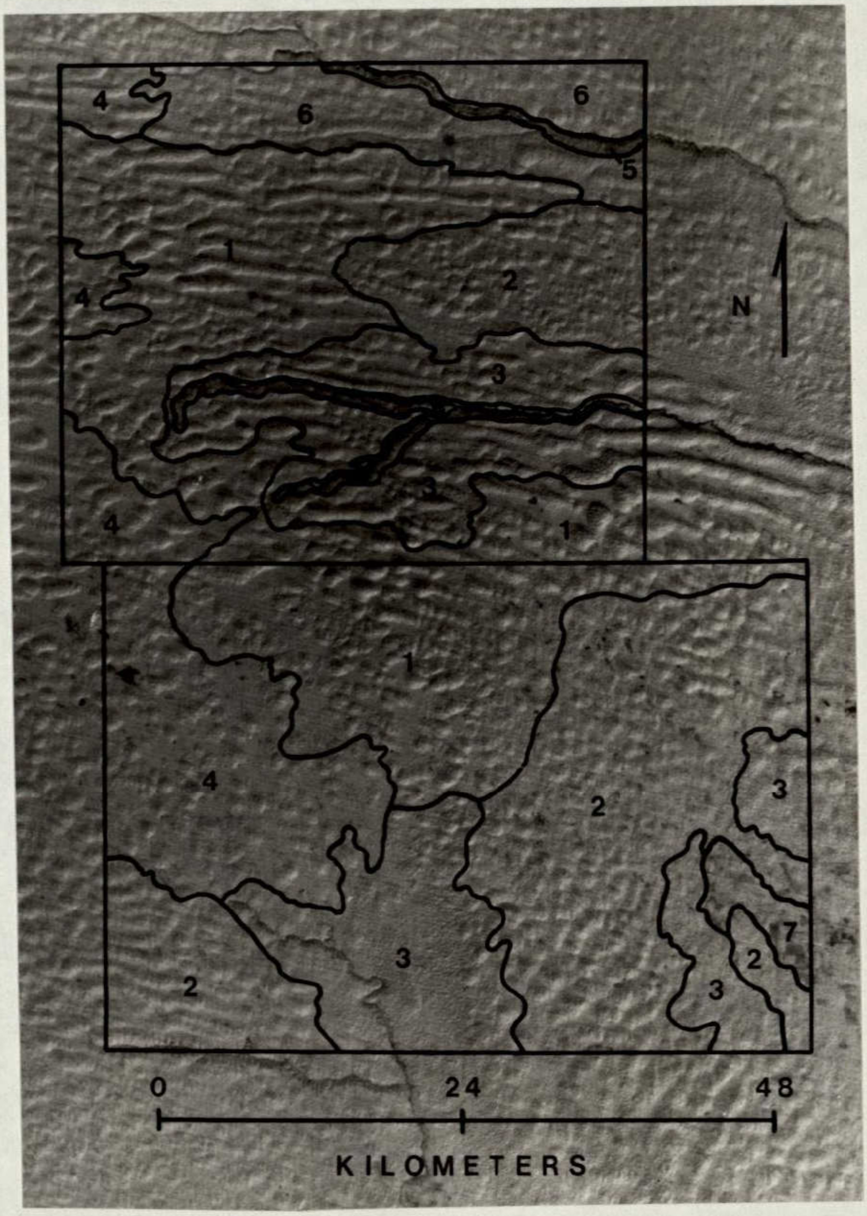


association where subirrigated Loup occurs along major drainageways (figure 3). In addition, land use patterns made it possible to delineate the Anselmo-Valentine-Dunday association in the sandhills-loess border. Here finer textured Anselmo is used for cultivated crops (identified on the image as rectangular fields) in contrast to the general lack of cultivated fields on the surrounding rangeland.

Continuous snow cover and a solor elevation of 21° on January 9, 1973, provided shadow patterns which made it possible to interpret dune topography associated with the Valentine soils or the intervening dry valleys associated with Dunday or Anselmo soils. Near-infrared reflectance in band 6 from the snow covered landscape gave the best enhancements of topography (figure 4). Boundaries of soil associations in relation to snow-enhanced topographic features within the counties under study are shown in figure 4. In general, the boundaries correspond to soil associations delineated on the published soil association maps, but certain boundaries were modified slightly to correspond to interpretations of landscape features defined for the associations (table 6).

In McPherson County, the Valentine hilly association has a characteristic texture on the image resulting from the short, steep slopes of a choppy, wind-shaped landscape.

Figure 4. Snow Covered Landscape in McPherson and Hooker Counties Utilized for Topographic Determination of Soil Associations.



more than 31 meters above the valleys, and transitional, gently rolling terrain is absent between the slopes of major dunes and the nearly level valley floors. Since the gently rolling terrain between the major dunes and the valley floors of the Valentine-Dunday association probably cannot be distinguished from valley floors on the snow-enhanced imagery, valleys in the Valentine-Dunday association appear wider than valleys in the Valentine-Anselmo association. This interpretation was supported by observations made from an aircraft flying at low altitude over the area.

Hooker County is adjacent to McPherson County and shows a similar pattern of soil associations on snow-enhanced imagery. Landscape patterns of major dunes and intervening dry valleys correspond to the Valentin-Dunday association and the Valentine-Anselmo association. As in McPherson County, however, valleys in the Valentine-Dunday association appear wider than in the Valentine-Anselmo association. In contrast, the Valentine, rolling association in Hooker County consists of smooth, low dunes separated occasionally by narrow valleys, and these characteristics differentiate this association from the Valentine-Dunday association and the Valentine-Anselmo association. Subirrigated valleys identify the Valentine-Elsmere-Gannett association.

Image interpretation of the Valentine, hilly association is somewhat different in Hooker County than in McPherson County. In McPherson County, the short, steep slopes of the Valentine, hilly association are not associated with major dunes. In Hooker County, however, shoppy, wind-shaped terrain is superimposed on large, east-west trending dunes. Consequently, the characteristic texture of the Valentine, hilly association is evident across the major dunes. The large dunes represent the oldest dunes in the Sand Hills region and were probably formed during early Wisconsinan time. Their rough surfaces, however, represent the youngest generation of dunes that occur as choppy terrain within the Sand Hills region. Similar relationships among soil associations and image patterns were evident on satellite imagery of Thomas County located immediately east of Hooker County.

Relationships established among soil associations in McPherson, Hooker, and Thomas counties and imager patterns acquired by LANDSAT 1 were used to construct a soil association map of a portion of Cherry County, Nebraska. Cherry County is adjacent to Hooker County on the north. A published soil association map developed by conventional methods and comparable to the soil association maps of McPherson, Hooker, and Thomas counties was not available for Cherry County.

Broad areas of the Valentine-Elsmere-Gannett association and narrow areas of the Valentine-Dunday-Loup association along major drainageways in Cherry County were identified on images acquired in band 5 by LANDSAT 1 on May 14, 1973. Subirrigated valleys within these associations were interpreted from the dark tones in contrast to the lighter tones of the adjacent well-drained soils. Choppy terrain interpreted on the basis of its characteristic texture on snow-enhanced images obtained in band 6 on January 9, 1973, was grouped in the Valentine, hilly association. Areas with major dunes and intervening dry valleys were grouped in the Valentine-Dunday association, and smooth, rolling dunes were included in the Valentine, rolling association. The Valentine-Anselmo association and the Anselmo-Valentine-Dunday association were not identified within the portion of Cherry County.

The map was evaluated by comparing the boundaries of soil associations with detailed interpretations of soil patterns on high altitude color infrared aerial photography obtained along a north-south strip 24 kilometers (15 miles) in width across the center of the area, and by the field examination of soil profiles at selected locations within this strip. In addition, the general pattern of soils was checked against an early soil survey of Cherry County based on field work done from 1936 to 1940. Although the nomenclature of soil taxonomic units used in the early survey was not entirely consistent with the recent soil surveys of McPherson, Hooker, and Thomas counties, the basic patterns of soils and landscapes provided a useful comparison. These procedures confirmed the general accuracy of soil association boundaries visually interpreted in Cherry County from multi-temporal LANDSAT 1 imagery.

Soil Subgroup Delineations

Soil Subgroups Based on Color Infrared Aerial Photography

Visual interpretation of high altitude aircraft color infrared photography showed a good relationship between vegetative patterns on the photography and the soils of the area as indicated by existing soils maps. Existing soils maps of a portion of Cherry County, Nebraska, were photographically reduced to the same scale as the aerial photography on clear-base positive transparencies. Overlaying these map transparencies on the aerial photography showed three distinct vegetative patterns associated with certain soils. Grouping of the individual soil series associated with these vegetative patterns on separate overlays showed these groupings to be related to soil subgroups as described in the USDA soil classification system. Table 7 shows this series-subgroup relationship.

Table 7. Major Soil Taxonomic Units within the Sand Hills Region of Nebraska

Series	Subgroup and Family	Soil Drainage Class
Valentine	Typic Upstipsamment, sandy, mixed mesic	Somewhat excessively drained
Dunday	Entic Haplustoll, sandy, mixed mesic	Well-drained
Anselmo	Typic Haplustoll, coarse loamy, mixed mesic	Well-drained
Elsmere	Aquic Haplustoll, sandy, mixed mesic	Somewhat poorly drained
Loup	Mollic Psammaquent, sandy, mexed mesic	Poorly drained
Gannett	Typic Haplaquoll, coarse, loamy, mixed, noncalcareous mesic	Poorly drained

The bluish-gray and white mottled pattern of the aerial photography formed one distinct vegetative pattern. Conversion of the outdated soils map nomenclature depicted by this pattern to current nomenclature indicated that the Valentine Hilly and Valentine Rolling series were depicted by this vegetative pattern. These series are included in the Typic Ustipsamment Subgroup.

A second vegetative pattern, predominantly red in appearance, formed another distinct grouping. Current nomenclature of soils represented showed Elsmere and Gannett to be the predominant soil series. It was readily determined that this grouping represented the subirrigated meadows frequently found in the interdunal depressions. For simplicity in handling of data, lakes, marshes, and ponded areas within the subirrigated valleys are included in this grouping. Visual evaluation indicated that the lakes, marshes and ponded areas can be separated from subirrigated areas. Aquic Haplustolls and Typic Hapliquolls are the soil subgroups represented by this pattern. Visual interpretation does not suggest a simple method of differentiating these two subgroups on the color infrared aerial photographs.

The third vegetative pattern characterized by a uniform blue tone involved two additional soil series. Current nomenclature identifies the series as Dunday and Anselmo. These series represent Entic and Typic Haplustoll Subgroups, respectively, and there are no apparent criteria for separating the two subgroups on the color infrared aerial photographs.

Range Site Identification and Delineation

Range Site Concept

Optimum forage production on rangeland requires specific criteria for management decisions. Since potential production varies with soil, climate, hydrologic conditions, and existing vegetation, criteria for management must take these factors into account. The classification of areas with similar factors into range sites identifies for the range manager the specific set of criteria he must consider in making management decisions for that site. Recognition of a specific range site on images acquired by remote sensing permits interpretation of factors influencing the range site. Variability in factors affecting the site, recorded as ground truth, can then be examined with respect to their influence on the imagery.

Range Site - Soil Association Relationship

The relationship of range sites to soil associations is shown in table 6. Each association is composed of one, two, or three individual soil series. Each soil series may be interpreted in terms of one or two range sites. Conversely, one range site may represent one or two soil series. If an individual range site can be isolated from all other by interpretation of topography, vegetative pattern, or a combination of these factors, it can be delineated on the imagery. Associations including only one major series, as the Valentine, hilly, and Valentine, rolling, represent only one range site. Associations including two or three soil series may represent two or three range sites. The distinction between sites, then, depends on topographic or vegetative differences within the association.

Range Site Recognition on High Altitude Color Infrared Photography

Interpretation of vegetative patterns on color infrared aerial photography provided the best capability for recognition of range sites. The characteristic patterns described in the previous Soil Subgroup section were correlated with known range sites. Sands and choppy sands sites were found to be associated with the bluish-gray and white mottled patterns. There appeared to be more white area associated with choppy sands sites as compared to sands sites, but it was not possible to differentiate consistently between these two sites. Since percent slope is probably the major difference between the two sites, it was not unexpected that consistent differentiation could not be accomplished. Valentine is the soil series associated with these range sites.

Subirrigated sites were associated with the predominantly red patterns. The red color is an expression of infrared reflectance from the vigorously growing vegetation of the subirrigated areas. Expression of the infrared reflectance is influenced by the management of the subirrigated area. If the area is mowed each summer, infrared reflections during the early growing season are stronger than those from grazed subirrigated meadows. In the grazed areas, dead vegetation from the previous season masks, to a varying degree, the infrared reflectance. Although this masking effect probably affects only a small portion of the total subirrigated area for the Sand Hills, the interpreter must be aware of this complicating factor.

Associated with most subirrigated areas are lakes and/or ponded areas where the water table is at or above the soil surface for a significant portion of the growing season. Open water is most often blue in color, the shade of blue being determined by water depth, water quality, and presence of reflections. Ponded or marshy areas where open water is relatively shallow and may recede below the soil surface usually is dominated by emergent aquatic vegetation. The color of these areas varies from deep red to black. On a given photograph, the ponded or marshy areas may be separated from the subirrigated areas. However, this stratification was not attempted on a routine basis. Elsmere, Gannett, and Loup are the soils associated with the subirrigated range site.

Sandy range sites are associated with the rather uniform blue tone of the aerial photographs. These areas are distinguished from the sands and choppy sands by an apparent lack of any mottling in the pattern. Although there may be sufficient infrared reflectance to cause some red color on photo patterns of these sites, there is generally not enough red color to confuse this site with the subirrigated site. For example, Site 4 has a relatively high level of production, yet did not show red color intense enough to suggest a subirrigated site even with spring regrowth after a late summer mowing for hay. It might be possible to confuse a lower producing subirrigated site which is grazed with a sandy site. The aftermath remaining after grazing could conceivably mask enough infrared reflectance to give the appearance of a sandy site in a high level of production.

Range Site Recognition on LANDSAT 1 Imagery

The same basic patterns for site recognition are evident for LANDSAT 1 imagery, in the form of color composites, as was evidenced in the color infrared aerial photography. The mottled pattern of the sands-choppy sands site is less distinct, as one might expect with the decrease in resolution associated with the MSS imagery. Sandy sites are shown in the uniform tone of the noninfrared reflecting vegetation. Subirrigated sites are indicated by the predominantly red color, with the lakes and marshes relatively distinct as blue and black respectively. Of the individual wavelengths, band 5 gave the greatest amount of information relative to vegetative density, but was suitable for identifying only subirrigated range sites.

Vegetative Biomass Estimation

General Observations

Differences in density of vegetative biomass are observable on the high altitude aircraft photography and LANDSAT 1 imagery throughout the Sand Hills region. Obvious differences are indicated by "fenceline contrasts," where one management unit produces less vegetative biomass than the adjacent unit across the fence even though the range site is the same on both sides of the fence. Equally as obvious, but less clearly defined, are differences in vegetative biomass over large areas. Part of these differences are due to the fact that different range sites produce different amounts of vegetative biomass in normal circumstances (i.e., a sands range site in good condition produces less vegetative biomass than a sandy range site in good condition). In addition, other factors such as past grazing history, fire, rainfall patterns, or other environmental conditions may have influenced the ability of the vegetation to maintain itself.

High-altitude Aircraft Photography

Differences in the density of vegetative biomass were readily observable on high-altitude color infrared photography. Fenceline contrasts were more readily visible and more frequently noted than on LANDSAT 1 imagery. Differences between large management units was also readily seen. No attempts were made to quantify differences in density on the aircraft photography because the proper spectrophotometric instrumentation was not available.

Satellite Imagery

Visual examination of MSS positive transparencies indicated a positive relationship between vegetative density and transparencies in the visible spectrum bands (4 and 5) and a negative relationship on the near-infrared bands (6 and 7). Preliminary optical density readings suggested that band 5 provided the best relationship between optical density of the transparencies and field measurements of vegetative biomass determined by clipped samples of the sites being studied. It was decided to emphasize evaluation of band 5 for the major emphasis of the imagery evaluation.

Optical Density Evaluation

Imagery from band 5 acquired for the test sites south of Valentine, Nebraska, described previously was evaluated by optical density measurements of 1:1,000,000 positive transparencies using a McBeth densitometer. Density of cloud-free images which corresponded to ground truth collection dates in 1972, 1973, and 1974 were read for the sites in this area. Readings represented average optical densities for ground areas of approximately 60 hectares (150 acres), well within the boundaries of the 240-400 hectare (600-1000 acres) management units studied. Table 8 shows a typical set of data for an image and its corresponding set of ground truth data.

Table 8. Relationship of Vegetative Biomass to Optical Density of Positive Transparencies for Selected Sites in the Sand Hills of Nebraska

Site	Site Category	Condition Class	Vegetative[1] Biomass LB/A, dry wt.	Optical[2] Density
b	Sandy	Poor	328	.49
c_1	Choppy Sands	Fair	534	.58
c_2	Subirrigated	Fair	1275	.64
a	Sandy	Good	1266	.67
d	Sandy	Good	1150	.64

[1] Field data collected 25 Jul 73
[2] Satellite overpass 26 Jul 73

Correlation coefficients were calculated for the sets of optical density-vegetative biomass data generated. Table 9, shows a relatively wide range of correlation coefficients (from .20 to .94) for the sets of data.

A plausible explanation for the wide range of correlation coefficients is that the optical density readings were over a large area of the site, resulting in evaluation of a less uniform area as compared to the area sampled in the field. A composite analysis, using all data for 1973 as one set, resulted in a low negative correlation coefficient (-.20). This low coefficient suggests that it is not valid to compare between images, although in some cases it was valid to compare data within images.

Table 9. Coefficients of Correlation Relating Optical Density Values of Positive Transparencies from LANDSAT-1, Band 5, to Vegetative Biomass on Five Test Sites.

Overpass Date 1973	Vegetative Biomass Range, kg/ha	Optical Density Range	Correlation Coefficient
May 14	134- 684	.74- .84	.20
June 1*	540-1167	1.04-1.21	.78
July 26	371-1444	.49- .67	.94
August 17	297-1432	.29- .45	.74
September 22	355-1413	.71- .88	.82

* Four sites only

Evaluation of Computer Compatible Tapes

Printouts from computer compatible tapes (CCT) of radiance values for MSS band 5 were used to obtain an average radiance value for an area 9 to 18 hectares (22 to 44 acres) in size at each test site. This area represented 20 to 40 picture elements for each site. These average radiance values were then used to calculate correlation coefficients for the resulting sets of radiance value-vegetative biomass data.

Table 10 shows relatively high correlation coefficients, ranging from -.79 to -.93 for the sets of radiance value-vegetative biomass data. The improved correlation with these data is most likely due to the smaller area evaluated on the imagery and to the fact that the area was more representative of the vegetative biomass sample taken in the field. A composite analysis, using the sets of 1972, 1973, and 1974 data as one set, showed a relatively high coefficient (-.85). This high composite coefficient suggested that valid comparisons could be made between data sets and even between sets from different years.

Table 10. Coefficients of Correlation Relating Radiance Values from LANDSAT-1, Band 5, to Vegetative Biomass on Five Test Sites.

Overpass	Vegetative Biomass Range, kg/ha	Radiance Value Range μW/sq cm	Correlation Coefficients
Sept. 4, 1972	825-2396	23.38-36.77	-.93
May 14, 1973	380- 684	36.33-45.53	-.92
Aug. 12, 1973	297-1432	26.57-38.83	-.83
July 5, 1974	876-1944	29.48-47.68	-.79

Relationship of Band Ratioing to This Study

Other investigations have utilized ratios of radiance values, usually between band 5 and band 6 or 7, to estimate vegetation density or biomass. These ratios correlate with "green" biomass and are influenced by near-infrared reflectance in band 6 or 7 from vigorous, healthy, green plants as well as visible red reflectance in band 5. In the Sand Hills rangeland, however, moisture stress may reduce near-infrared reflectance from the vegetation and may be misinterpreted to mean a decrease in vegetative biomass. Nevertheless, range plants under moisture stress are legitimate sources of forage, and vegetative biomass does not necessarily decrease during periods of moisture stress. Our results indicate that estimates of vegetative biomass in the Sand

Hills region using radiance values in band 5 along involve the average of the absorption of visible red light by live plant tissue and the reflection of visible red light by exposed sandy soil.

Lack of Complicating Factors

Estimates of vegetation density based on reflectance data are complicated by factors associated with the vegetation itself, and with the underlying soil when vegetation does not cover the soil completely. Reflectance is influenced by the kind as well as the density of vegetation. A number of investigators (Erb, 1973) have observed reflectance differences among species, not only between woody and herbaceous species, but between species of grasses. Growth form of vegetation also presents complexity in estimating vegetative biomass. Multiple layering of vegetation results in masking of understory layers in mixed-species rangeland. In addition, the presence of continuous vegetative cover can make layering a more critical factor than in areas where vegetation is less dense.

In areas where vegetative cover is discontinuous, reflectance characteristics of the soil surface may be a complicating factor in estimating vegetative biomass. Reflectance from a soil surface is influenced by the moisture content of the surface as well as by the amount of clay, silt, and organic matter in the soil.

Certain characteristics of the Sand Hills tend to minimize potential complexities in estimating vegetative biomass. Soils formed in the wind-sorted sands are relatively uniform and contain more than 85 percent sand over approximately 85 percent of the region. Because of the rapid infiltration and permeability of the sandy soils, the soil surface is normally dry in a matter of hours following rain showers, even in the subirrigated valleys where the water table is within the lower portion of the soil profile. Thus, the possibility of wet surface soil as a factor influencing reflectance is minimized.

Very few plant species are unique to specific soils or range sites within the Sand Hills region, except in wetland areas where relatively pure stands of water-tolerant species occur. Although the native vegetation consists of a mixture of species including short and mid-grasses, the distribution and density of Sand Hills plants is such that reflectance is not generally influenced by multiple layers of vegetation. Live vegetation constituted from 11 to 39 percent of plant cover on the test sites, indicating plant spacing such that there is little or no overlap of aerial portions of the plants.

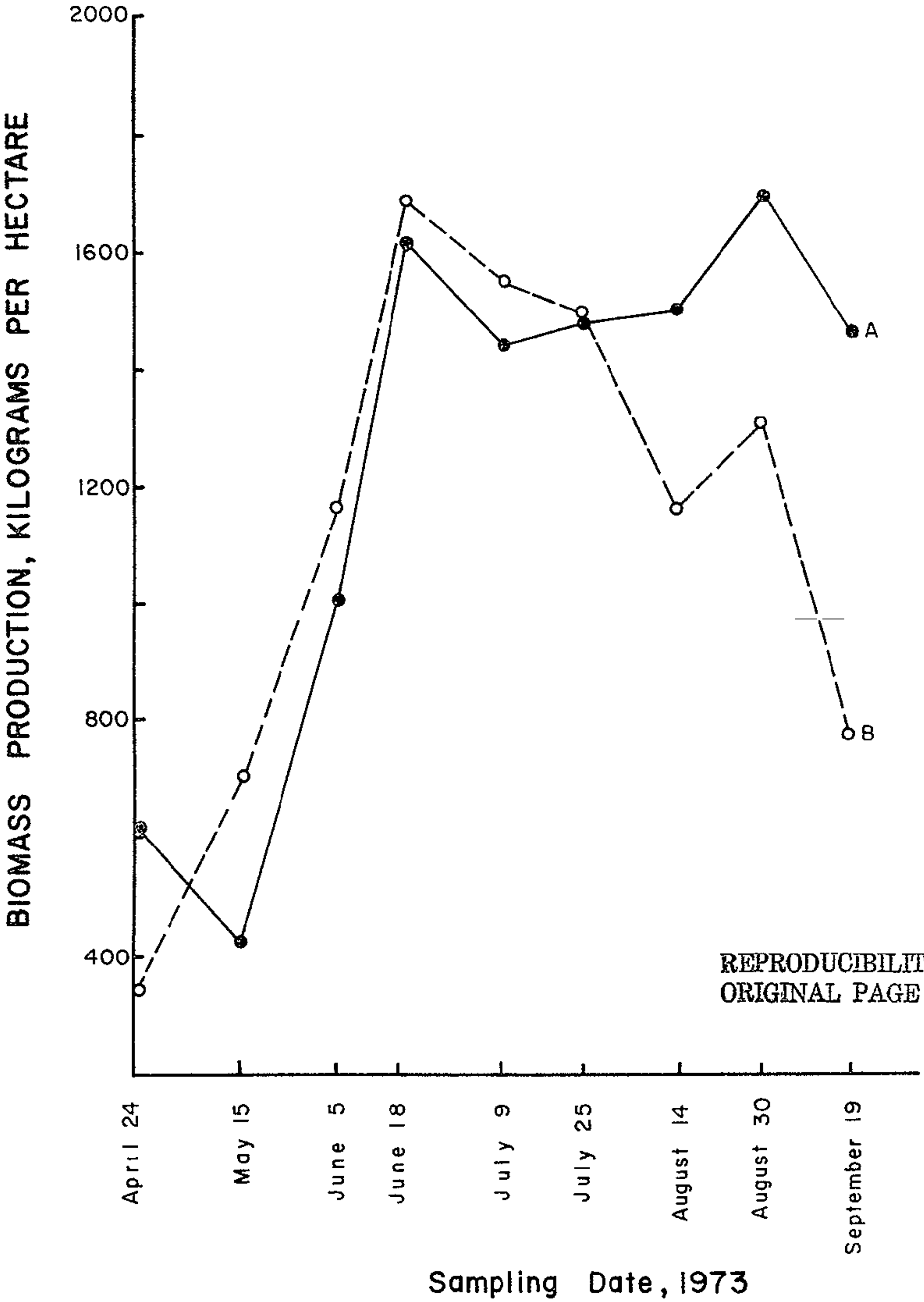
Vegetation surveys indicate a relatively high constancy (percentage of sites on which a given species is found) for the major forage producing species. Several species were shown by the survey to be common to all sites: *Calomovilfa longifolia* (prairie sandreed), *Sporobolus cryptandrus* (sand dropseed), *Bouteloua gracilis* (blue gramma), *Koeleria cristata* (prairie junegrass), and *Carex* species. Woody plants were relatively insignificant within the native vegetation. Consequently, the relative nonsegregation of species minimized the influence of species differences on reflectance values.

Relationship of Study Results to Management Decisions

Since range management involving animal stocking rates is based on the forage-producing capability of individual management units, estimates of vegetative biomass within management units are important for management decisions. Two sites were selected from the five sites studied in the Sand Hills region to illustrate management practices and to show management decisions based on traditional field estimates of forage production in comparison with satellite estimates of vegetative biomass.

One of these sites (site A, figure 5) was not grazed or mowed during the growing season of 1973. This permitted

Figure 5. - Vegetative Biomass Production on Two Sites Showing Ungrazed (Site A) and Grazed (Site B) Production Curves.



direct measurement of the maximum production of vegetative biomass. Clipping data obtained from site A at intervals during the growing season showed a typical curve for forage production.

A second site (site B) was subjected to grazing by livestock during the growing seasons so that a portion of the vegetative biomass was removed from the site. Thus, maximum production of forage could not be measured at site B, but was judged on the basis of maximum potential production and an estimate of vegetative biomass removed from grazing animals. The decline in vegetative biomass at site B after June 18, 1973, with the exception of small increases in responses to periodic rain showers, showed the influence of grazing in removing vegetative biomass (figure 5).

Data obtained at sites A and B were compared with range management decisions based on field criteria developed by the Soil Conservation Service, USDA, through extensive experience within the Sand Hills region. Site A showed good agreement between vegetative biomass measured by clipping and the recommended stocking rate. Clipping data from this site showed a maximum production of 1665 kilograms of vegetative biomass per hectare (1480 lb. per A). Recommended management for this site according to SCS criteria involved the utilization of one-fourth of the maximum production on one acre by one animal unit per month. Thus, 416 kilograms (370 lb.) of vegetative biomass would be utilized from site A per month under good management.

Assuming that one animal unit requires 848 kilograms (750 lb.) of vegetative biomass per month, each acre of site A would provide 0.5 animal units per month. This is the actual stocking rate recommended for site A by the SCS on the basis of field criteria.

In the case of site B, grazing was permitted on the site during most of the growing season. Thus, it was not possible to estimate actual maximum production either from clipping data or radiance values. Based on an SCS field estimate of "good" range condition class for site B, however, maximum production should approximate 3,390 kilograms per hectare (3,000 lb. per A.). Radiance values from band 5 correlated with clipping data indicated approximately 1,665 kilograms of vegetative biomass per hectare (1,485 lb. per A.) at site B during the period of peak production of June 18, 1973.

Application of SCS field criteria at site B indicated "close" grazing on June 18, 1973, suggesting that more than the recommended amount of forage had been removed. Following the recommended management practice of utilizing one-fourth of the maximum production per month, approximately 1,013 kilograms (2,250 lb.) of vegetative biomass should have remained at site B on June 18, 1975. Instead, the estimate of vegetative biomass from the radiance values as well as from observations in the field indicated that "close" grazing had removed approximately one-half of the vegetative biomass.

Thus, estimates of vegetative biomass from LANDSAT-1 were correlated with clipping data and with SCS range management recommendations based on judgments in the field. Tables 11 and 12 show the summary of satellite data analysis in relation to SCS estimates and recommendations for the sites.

Table 11. Summary of Satellite Data Analysis in Relation to SCS Estimates and Recommendations for Site A.

Field Measurement of Maximum Biomass Production	1665 Kg/ha
Radiance Value for Maximum Biomass Production	24.35 μW/sq cm
SCS* Recommendation for Biomass Utilization	416 Kg/ha
SCS Recommendation for One Animal Unit Month (AUM) of Biomass Consumption	835 Kg/ha
Calculated Stocking Rate Using Radiance Value	0.5 AUM
SCS Recommended Stocking Rate	0.5 AUM

* Soil Conservation Service

Table 12. Summary of Satellite Data in Relation to SCS Estimates and Recommendations for Site B

Estimated Maximum Biomass Production Based on Range Site and Range Condition Class	3390 Kg/ha
Radiance Value for Maximum Remaining Biomass	26.47 μW/sq cm
Field Measurement of Maximum Remaining Biomass	1665 Kg/ha
SCS* Recommended Biomass Utilization	25 percent
SCS Field Estimate of Biomass Utilization	50 percent
Radiance Value Estimate of Biomass Utilization	50 percent

* Soil Conservation Service

Identification and Evaluation of Rangeland Wildfire

Background

An unanticipated benefit of satellite imagery of the Sand Hills region was the use of the imagery to identify, locate, and assess areas of wildfire damage. Fire has a major ecological and economic impact on the rangeland in the Sand Hills. Immediate losses result from the destruction of vegetation, livestock, hay, equipment, fences, and bridges. The wind erosion potential created by removal of vegetation allows for the probably occurrence of long term effects. With the exception of local areas of subirrigated meadows, precipitation is the only source of soil moisture over about

89 percent of the region. Additionally, the water-holding capacity of the coarse-textured soils is relatively low, thus enhancing the potential for range fire when range conditions are dry. In view of the susceptibility of the sandy soils to erosion by wind, range management practices necessary to insure the rapid recovery of grass cover after a fire are essential to stabilize the soil and prevent blowouts.

Location and Assessment of Fire Patterns

Prior knowledge of the occurrence of rangeland fires in the Sand Hills allowed for rapid recognition of the fire patterns on LANDSAT imagery. If the imagery was acquired prior to any disturbance of the charred vegetative material by precipitation or vegetative regrowth, the pattern appeared black on positive transparencies of all MSS bands. Once the charred material had been worked into the soil by precipitation or scattered by persistent winds or masked by vegetative regrowth, the pattern was recognized by the abrupt change in optical density between burned and unburned areas on the positive transparencies. The burned area was located, using a transparent overlay of a standard U.S. Geological Survey map of Nebraska (1:1,000,000 scale) showing geographic features and township and range boundaries. Using major geographic features for positioning, the overlay was placed over a system-corrected image of the burned area prepared as a positive transparency with a scale of 1:1,000,000.

In one instance the pattern was only recognizable on the near-infrared bands. The acquisition of the imagery was approximately five months after the fire occurred. Ground examination of the burned area seven months after the fire occurred showed the only difference to be a lack of old plant residues in the burned area. Apparently the relatively strong near-infrared reflectance from the burned area resulted from new vegetative growth and the absence of older plant residues to interfere with reflectance.

Measurement of acreage affected by fire can be accomplished by the dot-grid method. Using grids of 64 and 256 dots per square inch, an average of four determinations (two with each grid) gave a measurement of 30,560 hectares (76,480 acres) within the burned area for the above mentioned pattern. Previous estimates of the burned area made in the field immediately after the fire ranged from 30,000 to 48,000 hectares (75,000 to 120,000 acres). Thus, satellite imagery can facilitate locating and measuring the extent of range-fire damage, information needed to implement disaster relief such as deferred grazing payments.

Monitoring Recovery from Fires

Because satellite imagery can be used to determine relative levels of forage production in the Sand Hills, it becomes a tool for monitoring the recovery of rangeland damaged by fire. Often areas affected by fire are not readily accessible on the ground. Should wind erosion become significant on these areas, immediate awareness is necessary before appropriate actions can be taken to combat the erosion.

Evaluation of Sand Hills Lake Water Quality

Background

The lakes of the Sand Hills region were chosen for study because they represent a rather unique situation with regard to factors affecting their water quality. In most cases, each lake represents a relatively isolated body of water unaffected by runoff into or drainage out of the lake. The hills and valleys surrounding the lakes are composed of soils high in sand and so porous that precipitation infiltrates directly into the soil profile and there is no runoff into the lakes. This precipitation is then added directly to the groundwater.

According to current theory, the lake levels are maintained by the interaction of ground water with the water of the lake. This then restricts the influx of ions and other components of water quality degradation to atmospheric particles or components inherent to the surrounding groundwater. Wind agitation of the water surface usually only increases sediment loads of near-shoreline water. All of the above factors tend to make Sand Hills lake rather stable in terms of water quality and excellent sources of data for investigating the relationship of water quality parameters to satellite data.

Visual Evaluation

Information from several sources (Sand Hills Lake Survey, 1960; McCarraher, 1970; Personal Communication) indicated a wide range in the amount of dissolved ions in Sand Hills lakes. Examination of these lakes on high-altitude color infrared photography showed variations in color. In many cases, however, these differences were due to the reflection of light from the lake's surface. This inconsistency in appearance indicated that any attempts to quantify the optical densities of the lakes from the photography would be meaningless. Since reflection was not a problem with the satellite imagery, it was also examined.

It was possible to see density differences among the Sand Hills lakes on imagery in all bands. Surface area of the lakes was most apparent on band 7. The greatest differences in density appeared on band 6. On the two bands of the visible portion of the spectrum (4 and 5) lake outlines were not distinct, making it difficult in some instances to identify the lakes themselves.

Ground Truth Collection

Based on the ability to distinguish visually differences in reflectance among Sand Hills lakes, it was decided to collect and analyze water samples from six lakes in the Valentine, Nebraska, area which represented the complete spectrum of water quality. Table 4 lists the names, locations, and sampling dates of the lakes sampled. Immediately upon collection, a pea-size lump of Thymol was placed in each sample to prevent microorganism activity from changing constituents of the sample prior to analysis. Analysis of the samples usually was conducted within 3 to 5 days after being collected. Sample dates did not correspond exactly to satellite over pass dates.

Optical Density Evaluation of Imagery

Initial imagery evaluation involved taking optical density readings from 1:1,000,000 positive transparencies with a McBeth densitometer for the lakes from which samples were taken. It quickly became apparent that there was not a consistent relationship between water quality parameters determined from sample analysis and optical densities measured from positive transparencies in band 6 and 7. This inconsistency is most likely due to the variability which is present in producing photographic products from the original tape data. It is extremely difficult to maintain film quality and development procedures within the narrow tolerances required to present the data accurately on a photographic product. The lake images also represent a rather extreme density range, further complicating the capabilities of the photographic products. The optical density evaluation did establish the general conclusion that as the quality of water decreases, the optical density of the water body on positive transparencies of satellite imagery decreases.

Relation of Computer Compatible Tape Data to Water Quality

Since computer compatible tape data do not contain the same set of restrictions as positive transparencies for data analysis, water quality in relation to the tape data was examined. A group of picture elements rectangular in size and of maximum size for each lake, was totaled to obtain an average radiance value for each lake sampled for each MSS band. These average radiance values were then compared to water-quality data in the form of total ions determined by lab analysis. Figure 6 shows a typical set of water-quality radiance value data. Correlation coefficients were calculated for all dates and all bands for which tapes were available. In all cases, coefficients were .87 or greater, with one exception. That one value was .60. Table 13 shows one set of correlations coefficients for a spring 1973 set of data. The relatively high correlation coefficients suggest that the radiance values from any of the four MSS bands relate directly to the total of those species of ions, shown by analyses of table 4, dissolved in Sand Hills lakes.

Table 13. Correlation Coefficients for Individual Band Data from Imagery of May 14, 1973 and Average Total Ions Dissolved in Lakes Sampled.

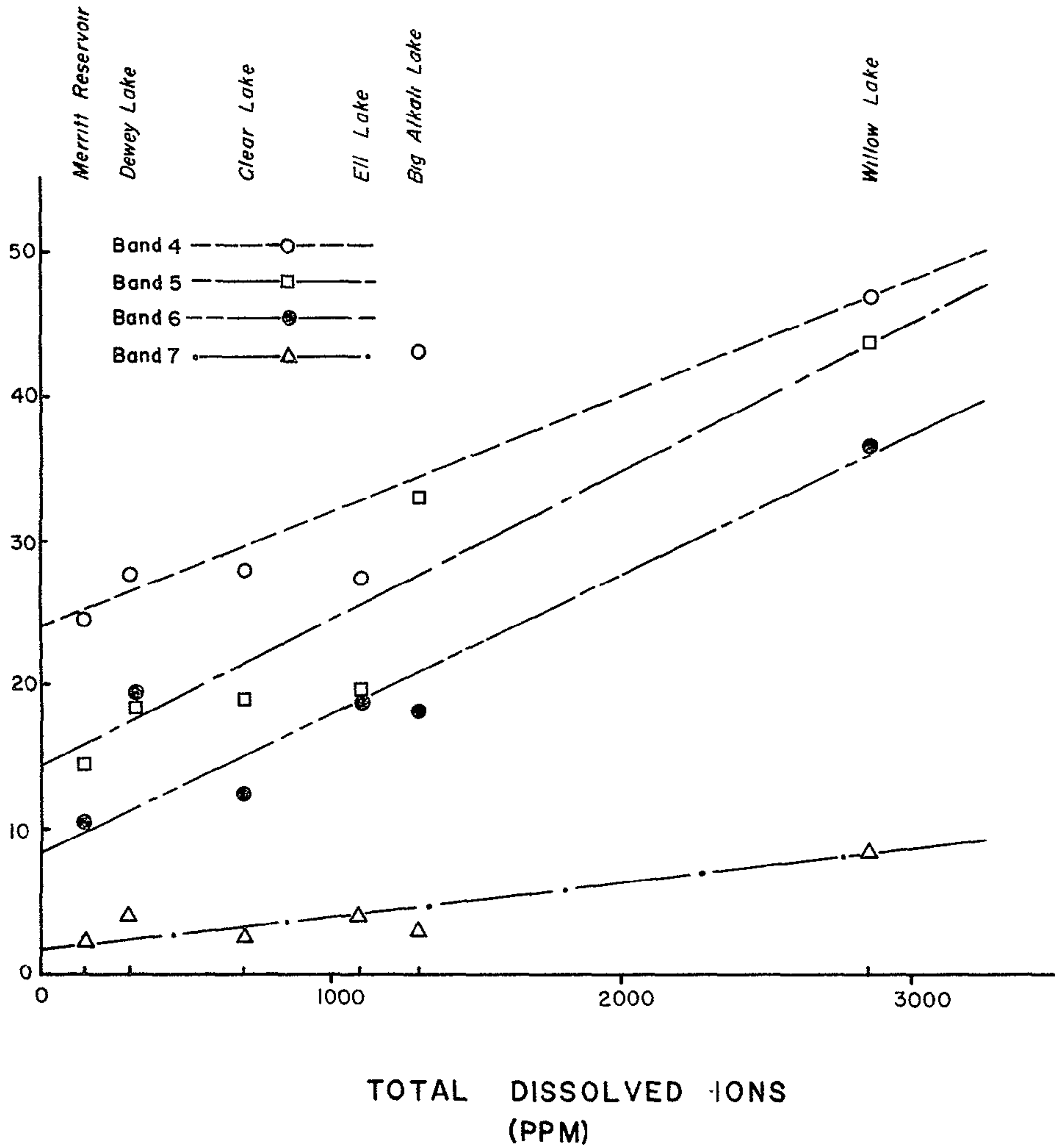
Band	4	5	6	7
Correlation coefficients	.89	.95	.93	.93

Evaluation of Center-Pivot Irrigation Systems

Visual Analysis of Satellite Imagery

Center-pivot irrigation systems are quite evident in much of the Sand Hills region on satellite imagery, particularly in July and August when they have full crop cover. Location with regard to type of site selected and indications of problem areas within the system itself were not readily distinguished. Usually density differences were detected in systems with loss of stand or ponding of surface water because of high water tables, but specific details were not discernible.

Figure 6. Relationship of Total Ions to Radiance Values for Selected Lakes in the Sand Hills Region of Nebraska.



Visual Analysis of Aircraft Color Infrared Photography

Detailed examination could be made of existing center-pivot irrigation systems on the high-altitude aircraft color infrared photography. Indications of lack of crop stand or ponding of water on the surface of the system were very evident. Where aircraft coverage was available prior to establishment of the system, the site characteristics could be assessed in relation to the subsequent degree of success of establishment of the system.

Two significant problems recurred on established systems as shown on the aircraft photography. In cases where the operator did extensive land leveling during establishment of the system, extreme difficulty was experienced in establishing crop cover on the disturbed area. Depending on what measures he took, the problem may exist for several years, and in a few cases caused the land to become unusable for irrigation because of large areas of severe wind erosion. The second problem was the accumulation of surface water as the system was operated during the growing season. This accumulation usually was traceable to a near surface water table which irrigation water caused to rise above the surface in the low areas of the system. In both cases, examination of the site prior to establishment of the system would indicate these potential problems. The decision of the operator becomes that of choosing a new site or making allowances for dealing with the problem created in establishing the system on that site. Figure 7 shows both successful and unsuccessful center pivot systems as shown on LANDSAT 1 imagery.

Figure 7. Portion of LANDSAT-1 Image Showing Successful Pivots in Black and Unsuccessful Pivots as Mottled Circles.

District. Consequently, a map showing the distribution of these features (fig. 8) was prepared from imagery obtained from MSS bands 5 and 7 on May 14 and 15, 1973 (images 1295-16564 and 1296-17023).

Wind Erosion Hazard

Overgrazing in the Sand Hills region is particularly critical in view of the fragile nature of the sandy rangeland and its potential for destruction by wind erosion. Continued overgrazing results in a sharp decrease in range condition class and increases wind erosion hazard.

LANDSAT 1 images from MSS band 5 obtained on August 17 and 18, 1972 (images 1025-16554 and 1026-17012), and May 14 and 15, 1973 (images 1295-16564 and 1296-17023), were used to map areas with less than 10 percent vegetative cover on these dates within the Upper Loup Natural Resources District (figure 9). Areas that did no recover to more than 10 percent vegetative cover by mid-May, 1973, are potentially hazardous in terms of wind erosion.

Blowout Land

Within the Sand Hills region, areas from 2 to 50 hectares or more in size that have been stripped of vegetative cover by wind erosion and that are actively eroding are readily interpreted from LANDSAT 1 imagery obtained during the growing season. A map showing the number of blowouts per township within the Upper Loup Natural Resources District (fig. 10) was prepared from LANDSAT 1 imagery from MSS band 5 obtained on May 14 and 15, 1973 (images 1295-16564 and 1296-17023). This map identifies areas where blowouts have severely reduced forage production and where erosion control is needed.

Center-pivot Irrigation

The production of forage irrigated by center-pivot systems to supplement forage produced by native rangeland established procedure for increasing the production of beef cattle within the Sand Hills region. One hectare of properly irrigated forage in the Sand Hills region provides an animal carrying capacity approximately equal to 20 hectares of dryland range. Imagery obtained from MSS band 5 on May 14 and 15, 1973 (images 1295-16564 and 1296-17023), was used to locate all center-pivot irrigation systems within the Upper Loup Natural Resources District and to identify these systems according to perennial forage crops or annual crops (fig. 11).

LANDSAT 1 imagery permits an assessment of center-pivot irrigation systems in relation to soil and topographic conditions within the Sand Hills region. Primary problems in establishing irrigated crops on the sandy soils involve wind erosion following severe land leveling, and the accumulation of surface water in subirrigated locations. Image interpretation has potential for delineating areas unsuited for the installation of center-pivot irrigation. In addition, an accurate inventory of center-pivot systems permits an analysis of energy requirements necessary to maintain irrigated production.

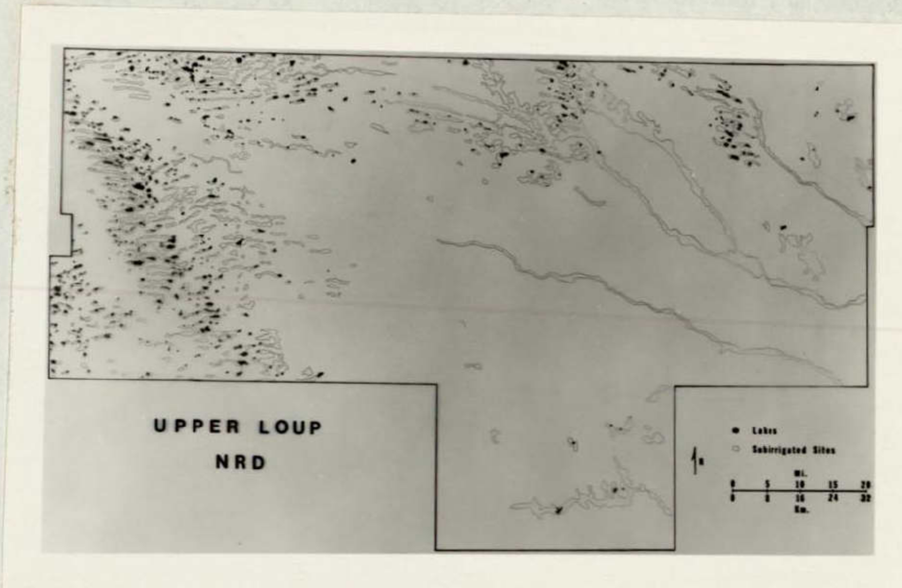


Figure 8. Distribution of Subirrigated Range Sites and Lakes Within the Upper Loup Natural Resources District, Nebraska.

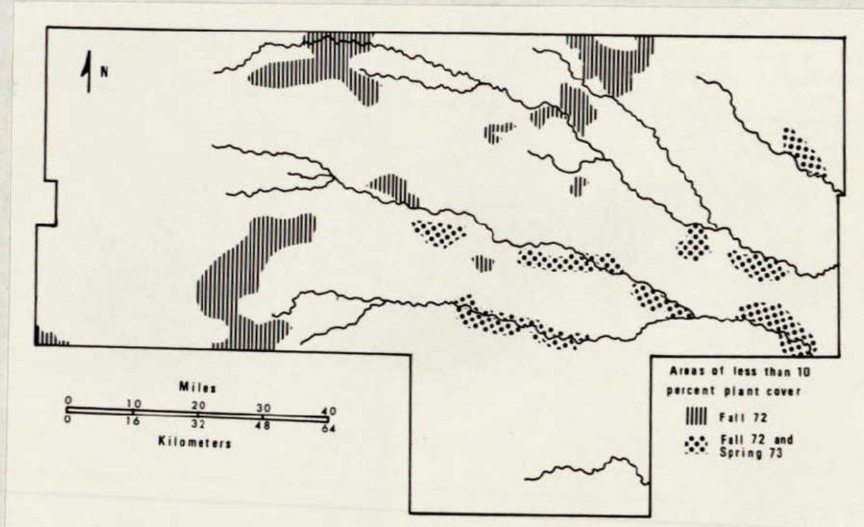


Figure 9. Distribution of Areas with Less than 10% Vegetative Cover on August 17 and 18, 1972 and May 14 and 15, 1973 Within the Upper Loup Natural Resources District, Nebraska. Areas in Which Vegetative Cover has not Increased Above 10% by Mid-May, 1973 are Susceptible to Wind Erosion.

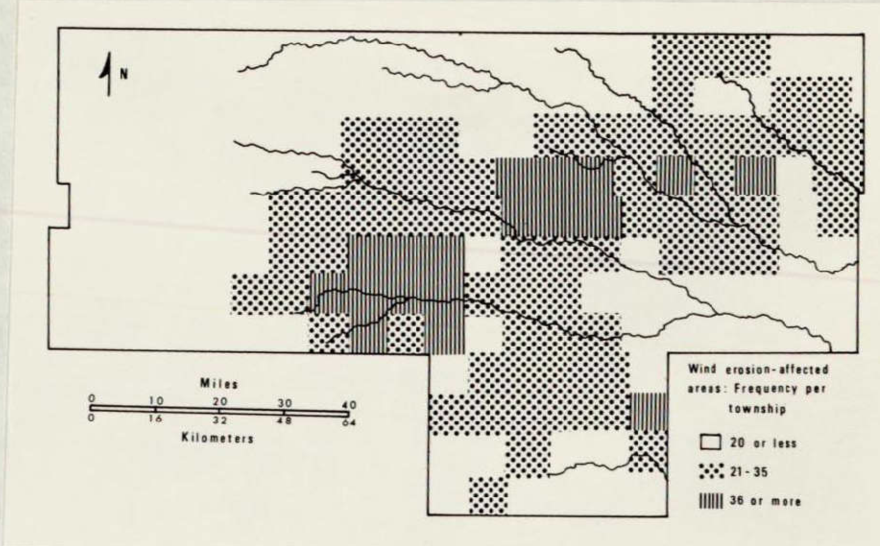


Figure 10. Frequency of Blowouts 2 to 50 Hectares in Size Within Townships in the Upper Loup Natural Resources District on May 14 and 15, 1973.

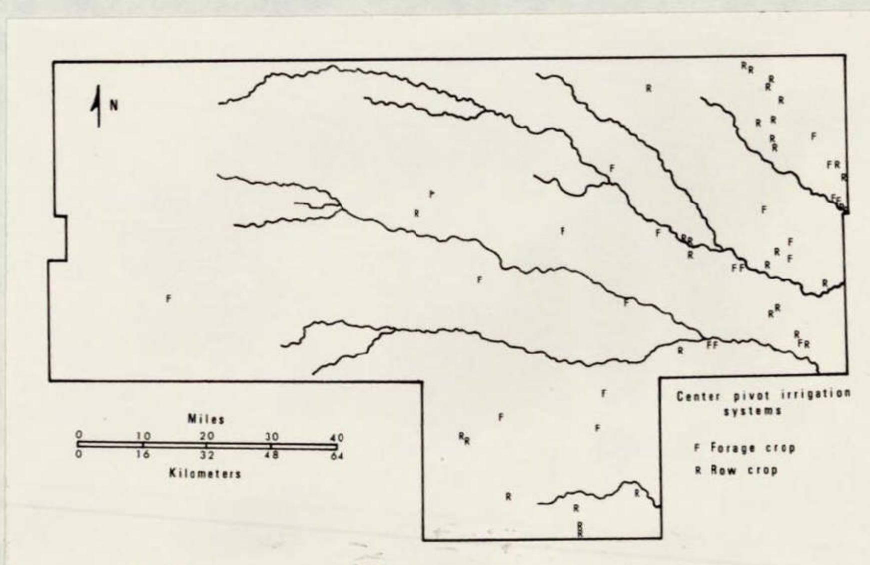


Figure 11. Distribution of Center-Pivot Irrigation Systems Identified According to the Production of Perennial Forage Crops or Annual Crops Within the Upper Loup Natural Resources District on May 14 and 15, 1973.

@abs The author has identified the following significant results. Evaluation of ERTS-1 imagery for the Sand Hills region of Nebraska has shown that the data can be used to effectively measure several parameters of inventory needs. (1) Vegetative biomass can be estimated with a high degree of confidence using computer compatable tape data. (2) Soils can be mapped to the subgroup level with high altitude aircraft color infrared photography and to the association level with multitemporal ERTS-1 imagery. (3) Water quality in Sand Hills lakes can be estimated utilizing computer compatable tape data. (4) Center pivot irrigation can be inventoried from satellite data and can be monitored regarding site selection and relative success of establishment from high altitude aircraft color infrared photography. (5) ERTS-1 data is of exceptional value in wide-area inventory of natural resource data in the Sand Hills region of Nebraska.